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STORM DRAINAGE AND URBAN REGION FLOOD CONTROL PLANNING

by

DARRYL DAVIS

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Stormwater within urban regions has generally been considered a "common enemy" so that the objective has been to dispose of the runoff as quickly as possible. The major components of stormwater management systems have consisted of storm sewers, open and closed conveyance conduits and occasionally detention storage and pumping facilities. It has been reported that the investment in storm drains is three times the investment in works to protect the flood plain and the annual damages from inadequate storm drains may well exceed the damage inflicted upon urban flood plains. (Continued)

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Formulation of stormwater management systems includes defining the planning objectives, determining the rainfall runoff characteristics of the area, selecting the performance criteria, developing and evaluating alternatives, and designing the implementation procedures. Storm drainage systems are a major planning task because of the large variety of management alternatives that are possible and because the impact of works on communities can be very great. Specifically this paper attempts to: (1) define the subject area and describe its characteristics; (2) review past concepts in storm drainage; (3) describe the current context of planning these systems; (4) describe the alternatives available and the implementation requirements; (5) discuss institutional factors including the federal interest and conclude with some observations on current planning approaches.

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STORM DRAINAGE AND URBAN REGION FLOOD CONTROL PLANNING[a]

by Darryl W. Davis[b]

INTRODUCTION

Stormwater within urban regions has generally been considered a "common enemy" so that the objective has been to dispose of the runoff as quickly as possible. In the past, disposition of stormwater has been by stormwater management systems that collect and convey the stormwater to some downstream location as rapidly as possible. The major components of stormwater management systems have consisted of storm sewers, open and closed conveyance conduits and occasionally detention storage and pumping facilities. The systems are expensive and have performed well in some instances and poorly in others. It has been reported (1)* that the investment in storm drains is three times the investment in works to protect the flood plain and the annual damages from inadequate storm drains may well exceed the damage inflicted upon urban flood plains.

Formulation of stormwater management systems includes defining the planning objectives, determining the rainfall runoff characteristics of the area, selecting the performance criteria, developing and evaluating alternatives, and designing the implementation procedures. Storm

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[a]Presented at the 21-25 October 1974, course on Urban Region Water Planning, held at the Board of Engineers for Rivers and Harbors, Fort Belvoir, Virginia.

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*References are tabulated at the end of the paper.

drainage systems are a major planning task because of the large variety of management alternatives that are possible and because the impact of works on communities can be very great. Competition for space and funds and good planning requires that drainage systems be considered integral parts of a broader urban design and that advantage is taken of all feasible joint development opportunities. In addition, there is growing concern that many problems should be amenable to nonstructural solutions that do not necessarily require large scale disturbance of the landscape. It is in this spirit that this paper has been prepared. Specifically this paper will attempt to (1) define the subject area and describe its characteristics, (2) review past concepts in storm drainage, (3) describe the current context of planning these systems, (4) describe the alternatives available and the implementation requirements, (5) discuss institutional factors including the federal interest and conclude with some observations on current planning approaches.

SCOPE OF URBAN STORM DRAINAGE

The Public Concern

Storm runoff in urban areas is of public concern because the movement and temporary storage of stormwater inflects damage to public and private properties and disrupts normal community activities. It has been stated (1) that most flood damages in cities occur along tributary streams, often where drainage areas are even less than 100 acres. An estimate (25) is that $340 billion (replacement cost) worth of public and private capital investment is exposed to flooding by the 100 year exceedence interval event. Local government has constructed $22 billion in drainage works for facilities that have cost between .5 million and 2.5 million per square mile to construct. Another author (22) has put the economic consequences of storm drainage and urban flooding in context in the following:

> "Consider the following figures; direct economic costs of urban flooding are estimated by the Corps of Engineers at about one billion dollars per year which increases to at least 1.6 billion per yeariif unobserved upstream urban flood losses are accounted for. American cities spend at least 1/2 billion dollars each year for necessary drainage construction. Storm drains built in conjunction with new streets and highways require 1.4 billion dollars per year. Federal flood control construction adds a tidy construction sum also. It is easy to account for direct losses and expenditures amounting to more than 4 billion dollars per year. The current 4 billion rate projects to over 8 billion per year within the next 30 years. By then this nation will have spend at least 180 billion dollars for construction or flood losses."

These figures, of course, include both storm drainage and the traditional area of flood control. The distinction that will be made hereafter is that "storm drainage and urban flood control" refers to removal of excess water

from lots, streets and protection along smaller streams and tributary areas within urban areas as contrasted with flood control required because of overflow of larger streams onto adjacent lands.

Storm Drainage Systems

Management of urban storm drainage consists of the programs required to reduce, to a socially acceptable level, the disruption of man's activities caused by stormwater runoff. Urban drainage management systems can include both physical works and management measures. The traditional works that have been used to collect, transport and dispose of storm drainage are quite expensive and construction frequently results in temporary major disruption of services within the area.

The physical system begins at the site where the stormwater originates, and terminates at the "disposal" point; the location where stormwater is no longer of social concern. Storm drainage systems can be considered to consist of two conceptual components. One component is designed to prevent the disruption of the normal social and economic activities during relatively frequent storm events. This portion of the system, which has been termed "the initial drainage" (2), conforms to the usual notion of storm drainage works. It is also referred to as the storm sewer system, curb and gutter system, convenience system and simply drainage system. These systems can rarely be economically designed to handle the infrequent events because of their high construction cost.

Another component includes the system that transports the storm runoff from rare and major runoff events and has been termed the major system. In many instances this system is unplanned and functions of its own accord. More attention is currently being focused on the need to plan for the functioning of the major system by physical works and complimentary nonstructural measures.

The physical works begin at the urban lot which is graded to convey stormwater to the street. The street is designed with curbs and gutters to transport stormwater along the edge of the roadways to the collector system. The collector system is usually a network of underground conduits that discharge into the main storm drains, which may not be but are also usually underground. The stormwater that accumulates from a number of collector systems is then discharged through an outfall to a major stream. In many systems the outfall discharges to remaining small natural channels that have been modified to function as integral parts of the storm drainage system.

In some instances the major drainage system has not been planned or designed and therefore functions in unpredictable ways. In a large number of cases, the initial drainage system is designed for a frequency storm (say of 5-year exceedence interval) so that when a major runoff event occurs, the stormwater seeks the path of least resistence (which is not the storm sewers), which means it flows down streets, over curbs, across yards, and at times through homes into old drainage channels. Major events usually inflict great damage and cause considerable inconvenience in urban areas.

Major drainage systems planned on a regional basis are designed to remove major runoff events using streets as primary conveyance facilities (temporarily disrupting traffic) with stormwater discharging into natural drainage channels that have been preserved in their semi-natural state by institutional controls. Detention storage has proven especially valuable during major storm events.

Scope of Planning

Planning of storm drainage systems is best performed within the context of the urban setting. The land use practices, which are a function of public policy and tradition, have a substantial influence on the amount of stormwater runoff. The transportation system has a considerable impact on the location and intensity of settlement, and, incidentally, on the hydrologic response of the system, and must be considered. Storm drainage planning must be interactive with these other planning activities in the urban setting. Considering other components of the urban system as "given" can result in poorly planned stormwater systems.

The location and type of storm drainage facilities are very much a public concern today because the works become permanent features of the community. As a consequence, the "people" side of developing and preparing alternatives is extremely important. Any construction that disturbs the landscape has some degree of impact on the environment and is therefore of great public and administrative concern. Good planning for storm drainage systems is a very complex process and requires application of the skills and techniques developed for planning the more major water resources systems.

URBAN HYDROLOGY

Definition and Role in Planning

The role of urban hydrology in planning for stormwater management is that of forecasting streamflow temporally and spatially throughout the urban watershed for use in establishing performance objectives and developing and evaluating alternatives. Urban hydrology refers to the technical analysis that is applied in order to develop the needed hydrologic information.

Rainfall-Runoff Process

The process of urban storm runoff can be conceptualized by following the movement of precipitation onto and through a watershed. During a storm event, precipitation falls upon a watershed in widely varying total amounts and rates. Each component of precipitation input to a basin is partitioned at the interface with the surface of the ground into surface runoff that may be termed overland flow and infiltration. The precipitation that infiltrates through the soil is "lost" to surface runoff, although in a few cases it may appear later in storm runoff. The overland flow accretes into small rivulets that grow into small drainage channels, then larger ones. The smaller and larger rivulets continue to aggregate into major channels and eventually into streams.

Water must have depth in order to flow and, as a consequence, some flow is temporarily stored on the surface of the watershed. This storage, termed natural storage, has an attenuating effect on runoff rates. In well developed natural watersheds there are many smaller and larger streams that provide considerable natural storage. In their natural state, the channels are

quite hydraulically rough and velocities and flow generally are not excessive. Further attenuation of the flow occurs because runoff is detained where it falls by surface vegetation and natural swales.

Effect of Urbanization

What happens when the watershed is urbanized? A great deal of the surface that previously was vegetation and natural ground becomes impervious by the addition of roofs, streets, driveways, walkways, and parking lots. The effects of this imperviousness are numerous. The precipitation cannot as readily infiltrate through an impervious surface so the volume of runoff increases. The surface is much smoother and thus hydraulically more efficient so that runoff occurs faster. In addition, less natural storage is operable which further increases the rate of runoff. The collector channels replace the natural channels with pipes that convey flow efficiently. The net effect on a watershed that has considerable urban development as compared to its natural state, is that of an increased volume of runoff and increased speed of runoff. This results in generally higher peak flows.

There is another important effect that can be referred to as the "system effect" or "timing effect." The flow at a concentration point in the system at an instant in time is the sum of the flow from the many components in the system. A watershed that has been converted from natural to an urban state can have its "timing" at concentration points significantly altered. The system effect at any point can result in either an increase or decrease in the flow rates depending on the relative timing effects.

A comprehensive table depicting the hydrologic effects associated with urbanization is contained in (3) and is as follows:

CHANGE IN LAND OR WATER USE		POSSIBLE HYDROLOGIC EFFECT
1. Transition from pre-urban to early urban		
Remove vegetation	-	Decrease transpiration.
Scattered housing construction	-	Increase storm flow sedimentation
Drilling wells	-	Lower water table
Add septic tanks	-	Increase soil moisture, and raise water table, some local pollution
2. Transition from early urban to middle urban		
Bulldozing land for mass housing	-	Increase storm flow sedimentation, elimination of small streams
Mass housing construction and street paving	-	Decreased infiltration, increased flood flows, lower ground water levels
Well abandonment	-	Rise in water table
Streamflow diversion	-	Decrease in streamflow
Discharge poorly treated sewage	-	Increase stream pollution, fish kills, inferior water quality and recreation
3. Transition middle urban to late urban		
Additional housing, streets, commerce and industry	-	Reduced infiltration, increased flood flows, curbs and gutter, lower base flow
More untreated sewage	-	Increased pollution
More well abandonment	-	Rise in water table
Increased population, water from other watersheds	-	Increased streamflow
Channels constricted	-	Increased flood damage
Construct sanitary drainage and treatment plant	-	Removal of water from area further reducing infiltration and recharge

Improved storm drainage	-	Reduced damages from flooding, increased stormwater flows
Deepened commercial wells	-	Lower pizometric head
Recharge wells	-	Raise pizometric head
Wastewater reclamation	-	Recharge aquifers

Quantifying the Effect of Urbanization

In planning storm drainage systems, one obviously has to plan for system performance for the conditions that will obtain when the system will be in existence. It is therefore quite important to have technology available for determing the effect of urbanization in quantitative terms and to be able to predict system performance under these conditions. This requires quite different analyses from planning major projects because historic streamflow records are no longer accurate indicators of what can be expected to occur in the future. Quite detailed and at times controversial analyses are required to develop the quantitative base needed for the planning of the storm drainage system.

There is agreement on the general effect of urbanization but considerable difference of opinion as to the magnitude. Most, if not all, investigators indicate that runoff will increase, but the specific magnitude of the increase is debated. A recent report (4) prepared by the U. S. Geological Survey for the Houston, Texas metropolitan area indicates the general order of magnitude of the effects of urbanization on floods. The report states that the peak flow increased by a factor

of 9 for an increase in imperviousness of from 1% (rural area) to 35% (completely developed urban area) for the 2-year exceedence interval rainfall event. For the 50-year exceedence interval rainfall event, the flow increases by a factor of 5 for the same increase in imperviousness. The less frequent events are indicated to have proportionately less increase in peak flow.

A report (5) prepared for the San Francisco Bay region indicates the following effect for urbanization:

RATIO OF PEAK FLOW FOR STATED CONDITIONS TO NATURAL FLOW

Exceedence Interval (years)	50% Development 50% Storm Sewered	100% Development 100% Storm Sewered
2	2.0	4.2
5	1.7	3.5
10	1.6	3.1
25	1.5	2.8
50	1.4	2.6
100	1.35	2.5

The results were obtained by regression analysis of runoff records for existing conditions within the Bay area.

A model has been developed (6) that is proposed for use in determining the drainage consequence of urbanization. This model uses the rainfall runoff procedures of effective rainfall determination, unit hydrographs and storage routing. A demonstration of the model for a watershed in San Diego County, California, indicates the following effects of urbanization. The results are for the 100-year exceedence interval storm.

RATIO OF PEAK FLOW UNDER STATED CONDITIONS
TO THAT UNDER EXISTING CONDITIONS

Watershed	Existing Land Use	Moderate Urbanization	Intense Urbanization
1.7 $mi.^2$	1.0	1.75	2.20
15 $mi.^2$ (without channel improvement)	1.0	1.2	1.5
15 $mi.^2$ (with channel improvement)	1.3	1.6	1.95

These two examples indicate that the amount of peak flow increase for urbanization is a function of the intensity of urbanization and of the exceedence interval of the event of interest. The intensity of urbanization relates to the amount of the watershed that is covered by impervious areas and the amount of the watershed that is storm sewered. The relative effect of urbanization for the less frequent events tends to dampen out for the following reasons: (a) for the increasingly rare events the watershed under natural conditions would be more saturated; (b) the channels would be more filled or overflowing; and (c) the flow velocities would be greater and therefore conversion to more efficient man-made systems has incrementally less impact. In other words, under natural conditions when the watershed is saturated, it is in effect quite impervious.

Analytical Techniques

The general state-of-the-art in developing information for the sizing of the initial drainage systems (sewer systems) is the simple concept termed "the rational formula." The rational formula is based on the assumption that the amount of flow contributing to the peak runoff is directly proportional to the intensity of rainfall for a duration that is equal

to the response time of the basin. This approach, while it has many shortcomings because it ignores a number of important system characteristics, continues to be used by drainage engineers because of its simplicity. A conservative estimate (23) is that better than 90% of the storm drain systems in the U. S. are planned using this technique.

Other procedures such as rainfall runoff analysis as performed by the Corps, are used but to a lesser extent and are subject to the uncertainties involved in predicting the state of the watershed prior to the runoff event of interest. More recently, attention is being directed towards the development and application of watershed simulation that are responsive to urban watershed peculiarities (7). These models are designed to account on a continuous basis for most of the moisture within the watershed and many use the simple concepts that had been used historically but because of the computer, the accounting is done on a much grander scale. In any event, the state-of-the-art in urban hydrology is probably such that the skill and judgement of the analyst are far more important than the technology that is used to develop the runoff hydrology.

Performance Criteria

It has been the practice (and still is) to express performance criteria in hydrologic terms and consider planning to be primarily the design of a system that will accomplish the performance criteria at least cost. In present day planning performance standards are still adopted and in a few instances performance is a variable to be determined as a result of the planning study. The table on page 18 is an example of performance criteria used in current planning.

PLANNING CONCEPTS

The Utility Concept

It is useful to develop an overall attitude or conceptual approach to planning stormwater management systems. A recent paper (8) describes planning in its historical context as "the utility approach." It is described as having the following components:

> "(a) basic indicators such as population or gross national product are extrapolated to project a future situation (b) the future is converted by per capita use or some similar factor into a demand or need for a product or service (c) the need or demand is considered to be a mandate for action and (d) plans were made to fulfill the demand and are justified by it."

The components can be related to planning storm drainage system as follows: (a) the basic indicators such as population and gross national product are projected for future conditions; (b) these projections are related to the intensity of land use, therefore one determines the future land requirement and a reasonable amount of this requirement is allocated to the watershed and/or flood plain under study, and (c) the demand, therefore, is to provide protection for this expected future land use and since this is a public service it is justified by its need.

The utility approach has some implicit logic that is not always considered by those applying it. They can be described as follows: (1) population and other basic trends are the inevitable consequences of static public values and choices, (2) the utility has the responsibility to meet the needs for services implied by the projections of such trends, (3) the hardware to provide the services is justified by the need. This logic and the utility approach in effect characterizes the planning and the provision of the facilities as that of always struggling to barely keep ahead of the

water shortage, the blackout, the flood, or whatever disaster fate has decreed. The major objections that society is raising to this approach are that projections are not choice independent. They are therefore subject to policy determination and changes in public attitudes. In short, projections are not without value judgements. The fault in the utility concept is that it can induce its own effects and thus fulfill its own prophecies. The concept also generally ignores, though less so as each day passes, the existence of alternatives other than hardware and that policy and public values can be changed in the face of a wide choice of strategies.

Resources Management Concept

The same paper (8) describes an alternative strategy as follows:

"(a) A societal situation in the future would be postulated not as the austensibly inevitable projections of trends but rather by a process of conscious choice. The planners model of the future would not be the awful eventuality (although that possibility must be contemplated) it would be the desirable objective.

"(b) Resources management would be viewed as a range of alternative opportunities to induce or facilitate the achievement of the accepted model.

"(c) Specific project proposals would be selected, designed, and justified in relation to their effectiveness in advancing the general resources management strategy."

This concept of resources planning seems quite appropriate under the social and institutional factors that are involved in planning major storm drainage works in today's urban setting.

This concept of planning has its roots in a comment made by Mr. Moe, director of the Department of Public Works in California, in a recent speech in which he said:

"The real problem facing all who propose public works projects is more than just gaining public support for specific programs. It is the necessity to develop these programs many years in advance of their construction while facing the threat that legislation enacted near the end of the process will be literally and retroactively applied to the entire planning cycle."

One could also argue that this is the major source of the migraine headaches planners are beginning to develop. Mr. Moe suggests that one of the key elements in bringing about a revised concept is that the value system of the past is rapidly changing. Under the proposed planning concept, the possibilities for the future would (hopefully) have been considered choice dependent. This should increase the likelyhood that plans will be in tune with public values.

Planning Goals

While a number of higher level goals have been competing for prominence as focal points in the planning process, the recently published Principles and Procedures for Planning Water and Related Land Resource Projects (9) reiterates that the major goals for federal level planning are those of (1) national economic development (economic efficiency from the national point of view) and (2) environmental quality. It further specifies that one must determine an optimum design based on economic efficiency and an alternative design based on environmental quality. It further requires that in general the benefit cost ratio for a recommended project must exceed 1. In other words, the broad thrust in planning is for continued economically efficient use of natural resources while observing the broader contributions that these facilities make to public well being and environmental quality.

An Example Approach

A planning approach developed by the Denver Regional Council of Governments (2) seems to embody to a great extent the preceding principles of resources management and general goals. The planning approach adopted consists of the following major premises, (1) the storm drainage system is a component of a larger urban system consisting of transportation, health care, police and fire protection, and other public services; (2) storm drainge is primarily a space allocation problem of where to transport and temporarily store the excess water; (3) storm drainage is primarily a resource out of place [in effect discarding the common enemy concept]; (4) planning should be multiple purpose and should consider multiple means [facilities can serve insofar as possible, other purposes as well as the drainage objectives, and many alternatives in addition to physical works are to be considered].

The overall concept further includes the recognition that a desirable storm drainage program will probably consist of provision for an initial drainage system that will manage the relatively frequent events so they do not inconvenience the community, and accommodation, in a rational way, of major drainage that results from the more extreme events. Specific definitions have been given to each of these components for a number of categories of potential land use. Performance criteria are as follows:

DESIGN STORM
(Performance Criteria)

Land Use	Initial Drainage	Major Drainage
Residential	2	100
General Commercial	5	100
Public Building Area	5	100
Airports	2-5	100
Public Facility Areas	5-10	100
Business Districts	5-10	100

The planning process is visualized as beginning with defining the problem so that the concerns can be organized into an overall set of planning objectives. These will be used to guide the development of overall drainage concepts and plans and specific designs. The Denver Council views the determination of user needs, which might more broadly be interpreted as regional planning objectives, as the responsibility of elective management, the attendent public agencies and the general public. The next step consists of developing alternative conceptual designs. This step receives the major share of the attention of the planners. The last component is considered to be the technical element and consists of the traditional design, construction, and operation of the works.

The definite emphasis placed on the conceptual design indicates substantial effort is devoted to the physical appearance and configuration of the works as components of the urban system.

The development of alternative conceptual designs results in one of two master plans that are viewed as the major tools for managing a drainage shed. One of the master plans is entitled a "Preventive Master Plan"

and is applicable primarily in rural areas that are beginning to experience development pressure. This master plan fits in well with flood plain management concepts where is is thought possible [believed anyway] to exert some influence over land use in the flood plain. The other master plan would be that developed for areas already experiencing considerable development and would contain a statement of overall objectives for the area, the works and programs that have been devised to accomplish the objectives, and the implementation schedule and specific recommendations for financing. It also includes the basis for flood plain definition for use in implementation of land use controls, if they are feasible.

A simplified flow chart that presents the interrelationships of the elements described in this approach is attached to the end of this paper.

ALTERNATIVES FOR STORMWATER MANAGEMENT

Alternative Concepts

There are basically two approaches possible in stormwater management; controlling water or controlling people (12). The first category fits within the usual notion of structural measures in which the basic objective is to prevent the water from contacting damageable property by physically controlling the stormwater. The second category is usually referred to as nonstructural measures that have the same objective of preventing the water from contacting damageable property. These measures are designed to keep people from building or living in flood plains or to cause those who do build to alter their use patterns in ways that will help reduce damages when floods occur.

This discussion will briefly focus on those structural measures that have been shown or demonstrated to be effective in controlling water, then shift to some comments on the nonstructural alternatives (management measures) which have been receiving increasing attention by planners and the public.

Structural Alternatives

Structural alternatives modify the movement of the stormwater throughout the urban area by storage or conveyance facilities. The key elements involved in planning stormwater management works are space, costs, and institutions for implementation. These few elements provide focal points for the multiplicity of alternatives possible for managing urban stormwater. The first element, space, is extremely important within an urban area because there are so many competing demands for its use. Space is at a premium

and is relatively expensive. It follows then that surface storage of runoff is expensive and difficult to justify for single purpose use. Conveyance of stormwater by means of open channels is also expensive. Conveying portions of stormwater underground is even more expensive. The need for open space within the urban settings provides some relief from this dilemma in that joint use of the space is a viable possibility.

The final important factor is the overall division of responsibilities among governmental units. While the division is not well defined, it very closely approximates their respective financing capabilities. The result of this institutional layerings is that the overall solution to the problem involves coordination and implementation by many levels of government. If one can accommodate these important facts then the plan that is developed will obviously be good and, importantly, implementable.

Consider the following sample costs for storage and conveyance within the urban setting, taken from (11):

STORAGE COSTS

Type of Storage	Cost in Dollars per Acre Foot
Open Reservoir (vacant land)	$ 3,000
Closed Conduit (within pipes)	100,000
Mine Storage (underground	8,000
Natural Flood Plain (vacant land)	4,000

CONVEYANCE COSTS

Type of Conveyance	Cost in Dollars per CFS Mile
Conventional Sewers (2 ft. diameter)	$ 7,500
(10 ft. diameter)	1,800
Rock Tunnels (10 ft. diameter)	1,200
(20 ft. diameter)	300
Open Channels (vacant land)	190

It is apparent that the least expensive storage is in open reservoirs and natural flood plains and that the least expensive conveyance is open channels or in some instances very large tunnels. These two elements, surface storage and open channel conveyance works, dominate systems studies for larger metropolitan areas.

The physical works alternatives can modify the rate of movement throughout the system, the usual storm sewer and flood control works, or detain the excess near where it falls (upstream). The works usually used to modify the movement through the system include sewers, storage reservoirs, canals, improved channels, pumping plants, tunnels and dikes or levees. The applicability and functions are well understood. Each of these works are very effective means of managing stormwater. The conveyance facilities (open channel) and storage works offer opportunities for joint use of space, such as for recreation, open space, wildlife habitat, conservation and other purposes.

One major consideration in structuring alternatives for use within an urban area is the appearance. Underground storm sewers cannot be seen; however, they are generally the most expensive conveyance mode. The least

expensive, surface conveyance, is also the most visible thus must be formulated carefully. The most frequently opposed storm drainage works are canalization (channel improvement) where an existing natural channel that performed satisfactorily under natural flow conditions is totally inadequate where peak flow is expected to increase from 5 to 9 times. The improvement consists of increasing the conveyance efficiency which in turn requires that the channel be protected against erosion from the increased velocities. The position of the opposition is that the natural landscape, an environmental asset, is being destroyed and replaced with an environmental liability (a rock or concrete lined chute).

The blue-green concept (15) has been used in joint storage-recreation planning. The storage ponds are designed such that they are surrounded by overflow areas that are treated as public open space or developed for recreation during nonstorm times. The overflow area is used during times of flood to temporarily store stormwater so that the resultant flow can be safely conveyed by the downstream channel. There are a number of technical problems associated with the proper design and functioning of these areas, but the concept is worthy of intense study.

The options available upstream are controlled primarily by local building codes and site development practices. The kinds of proposals that have been proffered include modifying curb construction so that runoff is detained, elimination of roof drains (those that discharge directly to sewers), detaining stormwater on roofs, in parking lots, etc., grading individual lots so as to encourage infiltration, detaining stormwater and planning for low maintenance channels and open space areas. Most of these

alternatives are viable only for areas that are not yet developed. A recent study (13) presents data on costs and performance for a variety of these upstream alternatives.

The results of a recent study (14) provides an illustration of the performance that may be expected from upstream adjustments. By making use of roofs designed with a top ring that would encourage storage, elevated plazas and parking garages for storage space, open grassy depressions and swales, it is possible to temporarily store stormwater on about 45% of the area within a low density residential location. The result is a predicted reduction in peak flow of approximately 33% for the 100-year event. By including the detention storage in swales along roads and contouring open space areas, an additional 38% reduction in peak flow is predicted. The author forecasts overall lower costs for storm drainage and public and private development. Implementation is almost exclusively a local non-federal prerogative.

Physical works would be easy to implement if the various publics and institutions were agreeable. The effort in planning these facilities revolves around assuring performance while accommodating the wishes of interested publics. On the other hand, the nonstructural alternatives have the characteristic that they are extremely difficult to implement even when a majority decision as to the desired course of action is in hand.

Nonstructural Alternative

Nonstructural alternatives include all management activities that are designed primarily to control people and reduce the incidence of damage and points of conflict in the flood plain. Some chose to label these

techniques as flood plain management although it will not be done here. In the context of this paper, flood plain management includes all activities related to managing flood losses and is simply the conceptual umbrella for both structural and nonstructural means for accomplishing management objectives. One of the originators of the term defined it thusly (16)

> "Flood plain management includes all planning and action needed to determine, implement, and revise plans for the best use of the flood plains and their water resources for the welfare of the nation."

The current interest in nonstructural management measures has its roots in the historical facts that even though the nation has continued to invest in large scale physical works to control flooding there has been a steady increase in the annual damages (17). This has been due in large part to unwise use of flood plains that continue to be subject to periodic inundation. People move onto flood plains protected by structures as if no further hazard existed, which can be viewed as setting the stage for a possible unprecedented disaster. This is no less true in the flood plains of minor streams. It is also contended (17) that people have become accustomed to governmental agencies paying damages when they occur. It has also become increasingly obvious that natural flood plains have an important ecological function to perform. Even though these concerns have resulted in considerable conflict, one author (18) has stated:

> "Conflict itself [as generated by the above situation] can lead to new innovations and new technology. For example, in the field of flood control, growing opposition to dams and other structural manipulations of stream flow is not going to reduce the incentive for action produced by the flood losses and potentials. Mechanisms to mobilize this incentive which provide relief with less threat of conflict, if not offset by other increases in decision making costs, will have a better chance."

Nonstructural works include but are not limited to a variety of land use and facility construction controls. The techniques most frequently described are zoning ordinances and building codes, and one should also include flood insurance within the means considered for encouraging compatible land use. Flood proofing and flood warning are other frequently encountered measures. Formulating viable nonstructural alternatives center around the problem of implementation. The implementation of nonstructural management measures requires careful consideration of an important point: as contrasted to structural means that can be undertaken on a majority rule basis, these measures usually require consensus by those involved and individual commitment to action.

James (12) has stated the situation related to nonstructural measures in a very forthright fashion as follows:

> "Taken as given the need to design nonstructural measures, a planner must recognize that he still needs surveys to obtain information in order to design an approach that will work. A flood plain regulation taken from a uniform code can no more effectively deal with flood damages than can the design of a dam known to work well in some other place."----------"A planner of nonstructural measures must ascertain what local factors will cause his design to function or fail, collect information on those factors, and use that information to recommend a design that has a good chance to succeed."

The specific management activities that will be needed to make effective use of nonstructural means must be very carefully designed for the situation and public at hand. It is well known that a "thou shalt not" declaration seldom has any chance of success. In most instances, ordinances that are poorly designed provide lawyers with adequate grounds for obtaining variances and once these begin to be granted on a continuing basis,

the ordinance is rendered ineffective. It is quite possible that the failures that have been observed resulted from the inadequate design of the implementation mechanism.

Sensitivity studies (19) of nonstructural management alternatives have indicated that flood proofing is a viable alternative and can be a major contributor to problem solution where flood-plain development consists of scattered buildings that are frequently flooded. Existing intensive development experiencing infrequent flooding of a severe nature does not lend itself to nonstructural resolution. In highly developed areas with an existing problem, structural measures are virtually the only feasible means of accomplishing a reasonable degree of performance. There is little need for land management in rural areas unless there is belief that there will soon be urban development or occupation of the flood plain by activities that would be incompatible with the risk involved. Land costs are sufficiently great in areas which are developed that early acquisition of land for future use as storage sites or conveyance routes could be considered as generally worthwhile. Reservoir storage is a useful component of drainage systems where large portions of the drainage area can be controlled. Such sites in urban areas are usually unavailable. Widely scattered small detention storage sites are more easily located and can be equally effective.

Flood forecasting is an alternative that in many cases is considered to be a service that should always be provided and is therefore not a viable alternative to other works. Consider for instance a flood-plain occupied by uses reasonably compatible with the risk, such as warehouse storage, parking facilities, or regional parks. With proper design, these facilities

would sustain very little damage provided adequate forecasts of runoff events would permit evacuation of items that would be subject to damage from the storm runoff. Flood forecasting as a management technique, however, is not inexpensive and is not necessarily technologically easily accomplished. In most instances the runoff characteristics of small watersheds are poorly known and as a consequence forecasts are quite unreliable. In addition, the response time of small urban watersheds is so short that adequate forecast lead times are virtually impossible. Nonetheless, with increased development of mathematical models and of remote data acquisition, forecasting systems could well be a useful component of an urban storm drainage system.

Combined Alternatives

Combinations of structural and nonstructural measures usually prove to be more optimal than either considered separately. A recent article in Civil Engineering Magazine (10) describes an approach that is termed "natural drainage" that is proposed for implementation in a newly developing area near Houston, Texas. The overall management approach includes both structural and nonstructural components. The natural drainage concept considers it essential that the existing flood plains be preserved as nature's easement which will be made use of at periodic intervals. It also recognizes that urbanization will definitely effect the response of the watershed and must therefore be controlled in some fashion. The specific criteria developed for this particular concept states that no development will be permitted within the 25-year flood plain of the small tributaries, that no development will be permitted within the 100-year

flood plain of the major streams, and in all instances the floor slab of any structure or public works will be located at least 1-1/2 feet above the 100-year flood level under developed conditions.

The developers recognized that the tendency will be towards increasing the amount and the rate of runoff and that the quality of the runoff will be lower. To counter these effects it is planned to include on-site detention, the use of local storage reservoirs, erosion control features, and strict control on the use of fertilizers and pesticides. In addition, since the ground water will be the water supply for the area, recharge areas are preserved and drainage is encouraged to percolate to keep ground water levels up. Also treated sewage is planned to be returned to surface water for recreation uses.

The primary objective is to retain the rain where it falls and encourage infiltration by utilizing the natural drainage system in its unimproved state. The wide, shallow swales will be preserved and native vegetation encouraged to retard flow. Small ponds and berms will be provided and drainage pipes will be used only where the natural system is inadequate.

It is anticipated that the system will be only about half as costly (on a unit basis) as a normal drainage system and the development is expected to be equally profitable to its developers. Cost for the usual drainage systems in this area have averaged near $1,200 per acre and the proposal is expected to cost about $600 per acre ($380,000 per mi^2).

INSTITUTIONAL CONSIDERATIONS

Division of Responsibilities

Storm drainage from the federal viewpoint is generally considered a local responsibility. Local responsibility can of course consist of a multitude of political jurisdictions. It is a fairly well established responsibility of municipalities to manage stormwater within the urban area. The stormwater management system within the urban area is usually provided by the land developers as needed to meet requirements of subdivision and building codes that are adopted by local government. This system can be viewed as the "initial drainage system," described elsewhere. Urban regions that encompass a number of municipal areas usually have drainage districts, or flood control and water conservation districts, or reclamation districts, or regional authorities whose responsibility it is to accept the storm outflow from municipal institutions and dispose of it outside the region. A few states have assumed responsibility for implementation of regional systems but most assume only funding responsibility (if they assume anything at all) as compared to a management responsibility. There is also federal interest in some cases.

The U. S. Soil Conservation Service has historically provided watershed protection programs and flood control activities under its PL 566 programs. Flood control works, reservoir storage and channelization, may be provided in urban areas provided that these facilities are components of watershed management plans. Under certain conditions the Department of Housing and Urban Development grants planning funds and the Environmental Protection Agency grants funds for constructing storm sewers within metropolitan areas.

The Corps of Engineers has responsibility for flood control and for "major drainage". Major drainage for urban areas (20), (24), (26) includes works that will provide "outlets" for drainage from organized drainage entities, such as municipalities and drainage districts. This has been further defined by policy to indicate that there is a federal interest in storm drainage works that will manage stormwater flows that exceed the 10-year recurrence interval runoff or the local design capacity, whichever is greater. In effect, the federal interest in many instances extends into regional urban areas in the same sense as many of the regional flood control and county organizations.

These multiple jurisdictions provide a great deal of flexibility in financing possibilities; however, the dispersion of responsibility tends to cause jurisdictional problems in the implementation phase. It is not uncommon for three, four, or even five separate jurisdictions to be involved within one urban region in the planning, design, and implementation of storm drainage works. A case in point is discussed below.

An Example - Institutions and Implementation

A storm drainge plan has been developed and much effort devoted to implementation for the Salt Lake City vicinity. Many of the institutional and jurisdictional problems involved in the planning, design, and implementation of storm drainage systems are evident. The surfacing of the problem occurred by the usual circumstances; a number of severe storms occurred that caused considerable damage. At about the same time, a regional planning activity had begun in earnest and it was recognized that development within the basin would aggravate flooding in downstream areas.

The situation was typical in that a problem was identified by a local jurisdiction (county) and a consultant was hired to prepare a master plan that was subsequently adopted by the local jurisdiction. After preparation of contract plans and specifications and just prior to contract award, litigation ensued that charged the county with lack of consideration of certain social values and cooperation with other governmental entities. Settlement of litigation was obtained and cooperation was initiated between the county and the Corps of Engineers. The Corps incorporated components of the master plan within their plans for the Jordan River and obtained authorization. The usual implementation by the Corps proceeded but was soon halted by litigation which also halted the local jurisdiction from implementation of other system components. The grounds for the litigation against both the Corps and the local cases were, interesting enough, primarily over design details. The overall concepts involved in providing relief from overflow due to excessive storm runoff and the integration of storm drainage with other components of the urban system were not disputed. In particular, the proposed riprap slope protection for the channel improvement was objected to by nearby residents. They perceived this as a destruction of the environmental and visual values for which they had originally moved into the area.

The circular process seems to be that initially, the small streams in their natural states were very attractive and people settled along their banks. As a consequence, runoff began to increase. As the runoff further increased, the streams were less and less able to provide adequate conveyance capacity. Soon the channels began to degrade and the overflow to cause damages. The downstream residents contended that the flood problem was being caused by upstream development and the upstream dwellers

assumed that excess water was a common enemy and were not very concerned over the issue of equity for their downstream neighbors. In this situation, equity between cause and effect became a central issue.

One report (21)described a specific situation as follows:

> "The people living on the creeks objected to their property being altered by channel improvements which they felt were solely intended to take runoff from the subdivision on the slopes above. On the other hand some dwellers on the 'high and dry' slopes were heard to comment 'if those people were stupid enough to build next to the creek they deserve to be flooded.'"

In the instance quoted here the problem was resolved by a redesign of the modifications to detention storage in conjunction with urban parks and selected reinforcement of natural channels. The difference in costs were within estimation error.

The present situation is that the county has recognized its inability as an institution to implement the system. A parkway authority has subsequently been created with jurisdiction over major streams in the area. The present state of implementation of the drainage system is uncertain.

An integrated Concept for Institutions

The institutional factors involved may seem to greatly complicate the planning and implementation situation since many jurisdictions are involved. However, on an optimistic note, one may consider that the multiplicity of political subdivisions provides the opportunity for a broadly based flexible approach to implementation wherein large scale regional planning is conducted in a way that permits local planning to make a logical contribution and thus allow implementation to be assigned to those units of government that have the authority and capability to do the job.

OVERVIEW

Public Perception of Drainage Problems

One reason planning of storm drainage systems is difficult is that drainage problems are low in the public's level of priorities. Concern (or interest) does not become focused until either a crisis has occurred (such as a big storm) or planning has progressed to the point where implementation has begun. At this point, it is usually very painful for the institution involved in the implementation to accommodate the points of view that have just surfaced. A possible device to reduce the severity of this occurrence is the recent programs in public participation in the planning process. It should be possible to better determine the public pulse through this mechanism. The very long lag time between planning and implementation reduces the effectiveness of even this program.

Key Points in Drainage Planning

Some of the key points that should be reemphasized in this discussion of storm drainage planning include the concept of the planning process itself and the critical factors involved in planning stormwater management works. The concept presented herein was that planning public works should be considered within the context of public policy and not be the inevitable result of past trends. We must consider explicitly the conditions under which our designs will be expected to function. We must address ourselves directly to the question of what is the expected future. Can we in fact design institutional and management mechanisms that will allow some measures of land use control? If so, then certain types of systems will be the

most advantageous. If this is not the case, then the systems we plan need to function differently.

Another major item is the need to address the means of implementation directly in the planning. Assuming "some one" will implement a plan if it is good enough just is not good planning. Storm drainage in the urban region is the responsibility of many. For the systems to function in any near optimum fashion all components of the system must be planned and implemented with due recognition for all other components. In other words, all plans should be developed and compatible on a hierarchical scale, beginning with those jurisdictions that have control over the streets and curbs and gutters to the jurisdictions that have control over the major receiving water areas.

With the potential of properly designed nonstructural measures, varying degrees of performance may be entirely appropriate. The criteria approach (a priori designation of acceptable performance levels) should be considered outmoded because it probably will not result in the optimum solution.

And last, and probably one of the critical and most important elements, how will the system look and what disturbance of the landscape is involved in its implementation? At this stage it cannot be overemphasized that the specific works themselves and their meshing with the remainder of the urban system, the neighborhoods and other social infrastructure must be in consonance with the public attitudes. The concepts of single purpose facilities designed with only functional considerations have caused most of the objections to implementations of regional storm management systems.

The Professional Planner

And what is the point of view of the federal planner? Is his point of view that of planning facilities that are implementable by the agency he is responsible to or is he planning to achieve the best solution with implementation one consideration in the overall development of the plan?

It is submitted that the latter is the only appropriate approach for the professional planner.

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